



Calhoun: The NPS Institutional Archive

Theses and Dissertations

Thesis Collection

2013-12

A cost analysis for life-cycle preventive maintenance, administrative storage, and condition-based maintenance for the U.S. Marine Corps medium tactical vehicle replacement

Goguen, Paul J.

Monterey, California: Naval Postgraduate School



Calhoun is a project of the Dudley Knox Library at NPS, furthering the precepts and goals of open government and government transparency. All information contained herein has been approved for release by the NPS Public Affairs Officer.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

<http://www.nps.edu/library>



NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

MBA PROFESSIONAL REPORT

A COST ANALYSIS FOR LIFE-CYCLE PREVENTIVE MAINTENANCE, ADMINISTRATIVE STORAGE, AND CONDITION-BASED MAINTENANCE FOR THE U.S. MARINE CORPS MEDIUM TACTICAL VEHICLE REPLACEMENT

**By: Paul J. Goguen
Scott J. Purcell
December 2013**

**Advisors: Simona Tick
Geraldo Ferrer**

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			<i>Form Approved OMB No. 0704-0188</i>	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE December 2013	3. REPORT TYPE AND DATES COVERED MBA Professional Report	
4. TITLE AND SUBTITLE A COST ANALYSIS FOR LIFE-CYCLE PREVENTIVE MAINTENANCE, ADMINISTRATIVE STORAGE, AND CONDITION-BASED MAINTENANCE FOR THE U.S. MARINE CORPS MEDIUM TACTICAL VEHICLE REPLACEMENT			5. FUNDING NUMBERS	
6. AUTHOR(S) Paul J. Goguen, Scott J. Purcell				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB protocol number ____N/A____.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			12b. DISTRIBUTION CODE A	
13. ABSTRACT (maximum 200 words) <p>This study provides a cost-based analysis of preventive maintenance and administrative storage for the U.S. Marine Corps medium tactical vehicle replacement (MTVR). In the years 1995–2013, the Marine Corps acquired approximately 8,750 MTVRs as overseas obligations increased. As the current conflicts wind down and the Marine Corps returns to lower force levels, the Marine Corps will see excess capacity in its MTVR fleet. This study begins the process of finding a solution to managing this excess capacity.</p> <p>Based on net present value analysis for various combinations of continued preventive maintenance and storage of excess vehicles over their life cycle, this study's findings contribute to determining the most cost effective method of handling the Marine Corps' MTVR fleet.</p>				
14. SUBJECT TERMS Medium tactical vehicle replacement (MTVR), United States Marine Corps (USMC), preventive maintenance, administrative storage			15. NUMBER OF PAGES 61	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UU	

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

**A COST ANALYSIS FOR LIFE-CYCLE PREVENTIVE MAINTENANCE,
ADMINISTRATIVE STORAGE, AND CONDITION-BASED MAINTENANCE
FOR THE U.S. MARINE CORPS MEDIUM TACTICAL VEHICLE
REPLACEMENT**

Paul J. Goguen, Major, United States Marine Corps
Scott J. Purcell, Lieutenant Commander, United States Navy

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

**NAVAL POSTGRADUATE SCHOOL
December 2013**

Authors: Paul J. Goguen

Scott J. Purcell

Approved by: Simona Tick, Co-Advisor

Geraldo Ferrer, Co-Advisor

William R. Gates
Dean, Graduate School of Business and Public Policy

THIS PAGE INTENTIONALLY LEFT BLANK

A COST ANALYSIS FOR LIFE-CYCLE PREVENTIVE MAINTENANCE, ADMINISTRATIVE STORAGE, AND CONDITION-BASED MAINTENANCE FOR THE U.S. MARINE CORPS MEDIUM TACTICAL VEHICLE REPLACEMENT

ABSTRACT

This study provides a cost-based analysis of preventive maintenance and administrative storage for the U.S. Marine Corps medium tactical vehicle replacement (MTVR). In the years 1995–2013, the Marine Corps acquired approximately 8,750 MTVRs as overseas obligations increased. As the current conflicts wind down and the Marine Corps returns to lower force levels, the Marine Corps will see excess capacity in its MTVR fleet. This study begins the process of finding a solution to managing this excess capacity.

Based on net present value analysis for various combinations of continued preventive maintenance and storage of excess vehicles over their life cycle, this study's findings contribute to determining the most cost effective method of handling the Marine Corps' MTVR fleet.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

I.	INTRODUCTION.....	1
II.	BACKGROUND	3
A.	MTVR VARIANTS	3
1.	MK23/25 Standard Cargo Truck	3
2.	MK27/28 Extended Cargo Truck	3
3.	MK29/30 Dump Truck	3
4.	MK31 Tractor	4
5.	MK36 Wrecker.....	4
6.	MK37 HIMARS Resupply Vehicle.....	4
7.	9-Ton and 16.5-Ton Load Handling System.....	4
B.	CURRENT MAINTENANCE PRACTICE	4
III.	LITERATURE REVIEW	9
A.	MILITARY MAINTENANCE TRENDS.....	9
B.	PRIVATE SECTOR MAINTENANCE	10
C.	SUMMARY	12
IV.	METHODOLOGY	13
A.	COST-BENEFIT ANALYSIS.....	13
B.	COST-BASED ANALYSIS.....	14
V.	COST-BASED ANALYSIS OF PREVENTIVE MAINTENANCE CHECKS AND SERVICES.....	17
A.	MAINTENANCE PROCEDURES	17
1.	Pre-Operations Check	18
2.	Scheduling-First Echelon.....	20
3.	Scheduling-Second Echelon.....	20
4.	Monthly	20
5.	Annual.....	21
B.	CHAPTER SUMMARY.....	22
VI.	COST-BASED ANALYSIS OF ADMINISTRATIVE PROGRAMS.....	25
A.	ADMINISTRATIVE STORAGE	25
1.	Pre-Storage Costs.....	26
2.	During Storage Costs.....	27
3.	Post-Storage Costs	27
B.	ADMINISTRATIVE DEADLINE	28
1.	Pre-Storage Costs.....	28
2.	During Storage Costs.....	29
3.	Post-Storage Costs	29
C.	CHAPTER SUMMARY.....	29
VII.	ANALYSIS OF FINDINGS	31
A.	ADMINISTRATIVE STORAGE PROGRAM VERSUS PREVENTIVE MAINTENANCE.....	31

B.	ADMINISTRATIVE DEADLINE	36
C.	SUMMARY	37
VIII.	CONCLUSIONS AND RECOMMENDATIONS.....	39
A.	RECOMMENDATIONS.....	39
1.	Recommendations for Marine Corps Logistics Command.....	40
2.	Recommendations for further research.....	40
	LIST OF REFERENCES	43
	INITIAL DISTRIBUTION LIST	45

LIST OF TABLES

Table 1.	Pre-operations Check Actions and Labor Required.....	18
Table 2.	Weights Used in Labor Cost Calculations	19
Table 3.	Monthly PMCS Actions and Labor Required.....	21
Table 4.	Annual PMCS Actions and Labor Required.....	22
Table 5.	Periodic Administrative Storage Costs Given Length of Time in the ASP	27
Table 6.	Comparative Costs Between PMCS and the ASP at Given Intervals (CY13\$)—22-Year Program	32
Table 7.	Comparative Interval Costs—12-Years Remaining	34
Table 8.	Total Cost to Maintain MTRV Fleet Given Combinations of the PMCS and ASP	35
Table 9.	Total Cost to Maintain MTRV Fleet Given Combinations of PMCS and the ADL	36
TABLE 10.	Maintenance Costs by Programs per Single MTRV for Given Interval	37

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

ADL	administrative deadline
ASP	Administrative Storage Program
CBM+	conditions-based maintenance plus
CM	corrective maintenance
CMC	Commandant of the Marine Corps
CY	calendar year
DoD	Department of Defense
DoN	Department of the Navy
EOM	echelon of maintenance
FY	fiscal year
GAA	grease, automotive and artillery
GCSS-MC	Global Combat Support System–Marine Corps
HIMARS	High Mobility Artillery Rocket System
LAV	light armored vehicle
MCO	Marine Corps Order
MBTF	mean time between failures
MBTM	mean time between maintenance
MEF	Marine Expeditionary Force
MMT	mean maintenance time
MPS	maritime prepositioning ships
MTTR	mean time to repair
MTVR	Medium Tactical Vehicle Replacement
NMC	not mission capable
NPV	net present value
OMB	Office of Management and Budget
PM	preventive maintenance
PMCS	preventive maintenance checks and services
TM	technical manual
USD L&MR	Under-Secretary of Defense for Logistics and Material Readiness
USMC	United States Marine Corps

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

We would first like to thank our advisors for their guidance throughout this project. Second, thank you to the officers and civilian professionals at Marine Corps Logistics Command for their interest and support for this project. Lastly, we thank the staff at the Acquisitions Research Program for the invaluable administrative support they provided. Without the aid of all of these people, this project would not have been possible.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

As the Department of Defense (DoD) faces decreasing budgets in the coming years, programs will face increasing pressure to manage costs and do more with less budget authority. The Marine Corps is facing a force reduction as the war in Afghanistan draws to a close, and the Corps' budget will not be immune from the reductions that will come with the drawdown.

Over the past decade, however, the Marine Corps has made significant capital investments in modernizing equipment to fight the recent wars. These investments are long-term. Responsible management of the assets entrusted to the DoD by the taxpayers is imperative. As the force is reduced, a cogent plan is needed to provide for the disposition of these assets so that they may continue to be available for future use.

The Medium Tactical Vehicle Replacement (MTVR) has been a major acquisitions program for the Marine Corps and Navy. With over 8,750 vehicles purchased, these trucks represent a significant investment by the DoD that must now be managed for the long term (M. Gavre, personal communication, October 23, 2013). The MTVR is a basic truck that provides a good general platform for study, as it contains many of the basic components of other vehicle platforms. The Marine Corps, therefore, may apply this project's findings to managing more specific platforms of vehicles.

Our research fits in the general area of identifying the most efficient ways to manage transportation assets as the nation draws down the military manpower and ends the recent wars. Clearly, as the force gets smaller, the number of trucks needed decreases. Simply disposing of these vehicles might not be a responsible option, as they represent a large investment of tax dollars.

By using a cost-based analysis of Marine Corps' vehicle maintenance, this study aims to determine the most effective use of excess MTVR capacity as overseas commitments draw down. These vehicles are subjected to strict maintenance procedures throughout their life cycles. Preventive maintenance is performed at designated intervals from fielding to retirement. As demand for these vehicles is reduced, the capacity

remains the same. Our interest is to examine how to efficiently manage that capacity. If vehicles are kept in units, ready for use, they have continuous maintenance requirements, whether the vehicles are driven or not. Potentially, with this excess capacity, this could result in unnecessary maintenance being conducted at a certain cost.

If a portion of the vehicle fleet were removed from the population and placed in storage, or if some efficient, conditions-based maintenance were adopted, this could potentially result in savings in the normal preventive maintenance cycle. To achieve its goal, this study analyzes several options for responsibly managing excess capacity of Marine Corps vehicles during peacetime so that they may continue to be available for use in an uncertain future. The results of this study aim to contribute to a better understanding of the Marine Corps' options in preventive maintenance and more efficient management of the vehicle fleet during periods of tightening budget authority.

II. BACKGROUND

The Marine Corps' Medium Tactical Vehicle Replacement (MTVR) was designed as a replacement for the M809/M939 series. The MTVR reached initial operational capability in 2001 and full operational capability in 2011 and has served as a primary logistics vehicle for the Marine Corps. More than 9,000 MTVR variants have been procured from the contractor, Oshkosh Defense (Oshkosh Corporation, 2013).

A. MTVR VARIANTS

The MTVR serves as a medium-duty, off-road capable truck that utilizes commercial automotive technology. It can carry up to 15 tons of cargo on paved terrain and seven tons in off-road conditions (Miller & Bryant, 2011). All variants come equipped with an independent suspension system and 20,000-pound self-recovery winch. Each MTVR can support the MTVR Armor System (MAS). Roughly 5,000 MAS kits have been procured.

1. MK23/25 Standard Cargo Truck

The MK23 is the base model of the MTVR. It consists of a 14-foot body with provisions for securing cargo. It is also equipped with troop seats (Oshkosh Corporation, 2013).

2. MK27/28 Extended Cargo Truck

The MK27 comes equipped with the same provisions as the MK23 but includes an extended 20-foot body for extra capacity (Oshkosh Corporation, 2013).

3. MK29/30 Dump Truck

The MK29 incorporates a hydraulically operated steel dump body on the basic frame. This body extends over the cab to protect the vehicle during loading (Oshkosh Corporation, 2013).

4. MK31 Tractor

The MK31 is the tractor version of the MTVR. It features a fifth-wheel hitch with a 32,000-pound vertical load rating. This can be used to pull a flatbed trailer for larger loads (Oshkosh Corporation, 2013).

5. MK36 Wrecker

The MK36 wrecker is essentially a tow truck variant of the MTVR. It features a boom winch that can lift and tow any other MTVR variant. It can also flat tow any vehicle up to 31 tons (Oshkosh Corporation, 2013).

6. MK37 HIMARS Resupply Vehicle

The MK37 is specifically designed to support the High Mobility Artillery Rocket System (HIMARS). This variant can transport two Multiple Launch Rocket System pods and is equipped with a material-handling crane on the rear of the vehicle (Oshkosh Corporation, 2013).

7. 9-Ton and 16.5-Ton Load Handling System

These variants of the MTVR are designed to transport cargo packed in intermodal containers, commonly referred to as CONEX boxes. The vehicles have provisions to automatically load and unload the containers for transport and delivery (Oshkosh Corporation, 2013).

B. CURRENT MAINTENANCE PRACTICE

The Marine Corps supports a plan for life-cycle support of its systems, providing a plan for the design, fielding, operation, and disposal of a system (United States Marine Corps [USMC], 2005b). By doing so, the Marine Corps can effectively plan through the planning, programming, budgeting, and execution process, and accurately determine the total ownership cost of a particular system.

Constant use of some equipment and storage of others can possibly lead to uneven wear and higher costs over the life cycle. To address this, the Marine Corps implemented a rotation policy for its equipment, as part of its Total Life Cycle Management Program.

Equipment, from vehicles to rifles, is divided between several categories: operational U.S.-based units, forward-deployed units, training units, and maritime prepositioning ships (MPS). Because training and forward-deployed units will incur higher use, the Marine Corps will periodically rotate equipment to units not deployed and to MPS, where use is significantly less. This process ensures even wear across a system throughout its life cycle. The scheduling of this rotation is delegated to the commanders of Marine Corps logistics bases. The MTRV maintenance program is part of this overarching rotation policy. The MTRV was designed to have a lifespan of 22 years (Miller & Bryant, 2011). Current maintenance practices are governed by *Marine Corps Order (MCO) 4790.7, Marine Corps Integrated Maintenance Management System Automated Information System, Headquarters Maintenance Subsystem*. MCO 4790.7 (Commandant of the Marine Corps [CMC], 1977) laid out the standard metrics used in maintenance planning for both preventive maintenance (PM) and corrective maintenance (CM). The metrics from the order are as follows:

- Mean maintenance time
- Mean time to repair
- Mean time between maintenance
- Mean time between failure

Marine Corps Order 4790.7 provides these metrics, as well as a legend of codes that aids in identifying and interpreting relevant data located within GCCS-MC.

Current maintenance is divided into five different echelons of maintenance (EOM). These echelons range from the operator at the individual unit performing minor upkeep to the depot level conducting major maintenance evolutions.

The most routine maintenance is referred to as preventive maintenance checks and services (PMCS). PMCS are completed at set intervals. An operator required to perform a pre-operational inspection of a vehicle is an example of this. Checks are scheduled both at pre- and post-operation of a piece of equipment and on a more time-specific schedule. These checks range from daily or weekly to annually and biennially (CMC, 1994). However, when operating conditions dictate, these periods may be reduced because of higher likelihood of early failure of parts.

As the name suggests, preventive maintenance is designed to be just that—preventive. By keeping up and ahead of the services for a particular vehicle, an operator is reducing the chance of failure on that gear. If something has started to fail, the inspection process is designed to catch the failure as early as possible in order to minimize maintenance downtime and associated costs.

While preventive maintenance is designed to be a proactive function, corrective maintenance is reactive by design. Corrective maintenance exists to fix failures of parts that have already occurred. This may be detected by a vehicle breaking down, during an inspection, or through the course of PMCS. Once a broken or defective part is discovered, the vehicle is placed in a not mission capable (NMC) status and given a reason. A vehicle can be NMC while it is waiting for repair parts. It can also be designated as NMC due to a lack of resources, such as manpower or funds, to fix the problem (CMC, 1994).

Once the source of the failure has been determined, the unit must determine the level at which the part can be repaired. If, for instance, an axle bearing fails, the technician must determine whether the bearing is a field-repairable part, meaning it can be repaired at the unit level. If not, it is depot-repairable and must be sent off to another unit at an increased maintenance time (CMC, 1994). At the higher-echelon maintenance facility, the part is analyzed for smaller parts of the system that may have failed and is repaired as necessary.

The schedule for preventive maintenance can be delayed. If a piece of equipment is placed in administrative storage, maintenance may be delayed under the provisions of that program. The ASP is designed to be a long-term solution. A piece of equipment that is placed in an ASP must remain in storage for a minimum of 12 months and is limited to 30 months maximum. While not bound by the PMCS schedule, some checks must still be performed. Maintenance must be performed on the equipment prior to inducting it into administrative storage. The equipment must then be inspected quarterly and exercised every six months. The PMCS checks must then be performed again once the equipment is removed from storage (CMC, 1994).

In order to assess best practices in operations and maintenance, the private sector may provide unique insights. The innovations of a profit-driven company should be monitored by the military as these innovations might be employed as efficiencies in the government sector. Some of the literature from the civilian sector is summarized in the next chapter.

THIS PAGE INTENTIONALLY LEFT BLANK

III. LITERATURE REVIEW

In this chapter, we present a review of the most relevant and current studies of both military and private sector maintenance practices. This review provides a foundation for the alternative comparison in the cost-based analysis presented by this study in chapter VII.

A. MILITARY MAINTENANCE TRENDS

In 2004, the Marine Corps nominated the Light Armored Vehicle (LAV) program to be one of the first systems as part of a new, proactive maintenance program across the Department of Defense (Department of the Navy [DON], 2004). The result was the establishment of the Condition Based Maintenance Plus (CBM+) program in 2007 (Under Secretary of Defense for Logistics and Materiel Readiness [USD(L&MR)], 2008). The CBM+ program includes new acquisition programs such as the C-17 Globemaster III and the F-35, as well as legacy programs such as the LAV and AH-64 Apache.

The CBM+ program is more concept than procedure. A system utilizing CBM+ may be used to combine practices that are already in place, such as oil analysis, with newer technologies like on-board sensors, to produce a holistic look at the status of a piece of equipment. Maintenance technicians at the unit level are aided by this practice as they spend less time performing maintenance that does not necessarily need to be completed. They also get a better idea of how their equipment is performing so that they might predict failures and intervene prior to failures occurring. This will save time in the long run by avoiding catastrophic failures.

Higher echelons of command can benefit from CBM+ by having the ability to look at a fleet of vehicles as a whole. In an analysis of fleet data, commanders can pull out trends in the fleet to identify large-scale problems. The commander can then direct individual units to take corrective action or even work with the contractor to find a fleet-wide fix for the potential weak point. This ability may lead to higher operational availability of an asset and lower life-cycle costs.

In October 2012, the Under Secretary of Defense for Acquisition, Technology, & Logistics updated the instruction for CBM+. The latest CBM+ guidance requires all new acquisitions programs to be supported by condition-based maintenance. One of the goals of the program is to “enhance materiel availability and life-cycle system readiness by reducing equipment failures during mission periods and identifying the best time to perform required maintenance, thereby increasing the operational assets” (Department of Defense [DoD], 2012a, p. 5). The CBM+ program currently includes only a limited number of programs throughout the DoD. The hope of the leadership is that use of this program across the board will increase readiness as well as reduce overall costs to maintain these systems.

B. PRIVATE SECTOR MAINTENANCE

Fornasiero, Zangiacomi, & Sorlini (2012) defined a product’s life cycle into the categories of beginning of life, middle of life, and end of life. Beginning of life includes the development and acquisition of a system. Middle of life is the actual use of an asset for its intended purpose. Finally, end of life addresses the retirement and disposal of an asset. This study focuses primarily on the middle of life portion of the product life cycle, as this is where the bulk of maintenance and services is performed.

A look at the private sector shows significant interest in maintenance practices. Haghani and Shafahi (2002) showed that maintenance is the second highest cost in a transit system. These costs can be up to 21 percent of the total operating expense. Given this number, a small reduction in maintenance costs can lead to a large overall reduction in operating cost.

Barnes and Langworthy (2003) studied the per-mile costs of operating a truck and found that maintenance costs accounted for 24 percent of total operating costs on smooth pavement and 27 percent on extremely poor pavement. These numbers were calculated for a fleet of 18-wheel trucks. This is probably the closest we can get to the Marine Corps’ fleet of MTVRs from the private sector. Given the Marine Corps’ MTRV operating profile of 70 percent off-road and 30 percent on-road, maintenance costs could be in the range of 26 percent of total operating costs. These numbers, however, are close

but slightly out of date. With improvements in engine technology and efficiency, and with significant increases in fuel prices, maintenance may be a smaller portion of operating costs today.

Fornasiero et al. (2012) and Bateman (1995) classified maintenance into different categories based on how problems are addressed. Reactive maintenance is performed only after a failure has occurred. Bateman explained that this is often the most costly type of maintenance, since failures that are allowed to occur are often catastrophic in nature (Bateman, 1995).

An early step to avoid the passive nature of reactive maintenance was the development of preventive maintenance. Preventive maintenance aims to avoid catastrophic failures by using regularly scheduled services such as inspections, adjustments, and lubrication at specified intervals (Bateman, 1995). Preventive maintenance theory can be seen in the current maintenance program used by the Marine Corps. Inspections and services are completed at set intervals in an effort to reduce the number of catastrophic failures, thereby reducing maintenance costs and asset downtime.

The private sector has made efforts to further the understanding of the final category, predictive maintenance. The development and incorporation of information technology has produced various decision-support systems that are designed to further reduce maintenance to what is actually required when it is required through various methods of monitoring a system (Fornasiero et al., 2012). This is a more proactive approach to maintenance and potentially leads to a reduction of unnecessary maintenance procedures.

The literature involving maintenance of vehicle fleets is primarily concerned with per-mile costs of fleet operation (Barnes & Langworthy, 2003) or the optimum scheduling of fleet routing and servicing (Haghani & Shafahi, 2002). The impact of proactive, predictive maintenance on fleet maintenance costs has not yet been researched in depth. Some research has been done in the field of continuous manufacturing processes; however the idea of condition-based maintenance remains new and relatively untested.

C. SUMMARY

The private sector has made advancements in recent years in using real time data to increase the efficiency of operations through smarter maintenance practices. The DoD has made some motions in this direction. However, only a handful of programs have been moved toward the CBM+ program. Thus, the DoD is still working towards leveraging the advancements in this area.

IV. METHODOLOGY

The goal of this research is to develop a cost-based analysis of several maintenance options available during the life cycle of a system: PMCS, ASP, ADL and CBM+. We specifically chose to analyze the MTRV program. The MTRV is one of the most widely used vehicles in the Marine Corps today. However, our analysis will provide an example of life-cycle maintenance cost analysis that can be applied to other systems.

A. COST-BENEFIT ANALYSIS

This research follows the general steps for a cost-benefit analysis. The process begins by specifying a set of alternative projects (Boardman, Greenberg, Vining, & Weimer, 2011). We limit our research to PMCS, administrative storage, and conditions-based maintenance to limit the research to something manageable in the time available for this research. These programs are also of particular interest to the Marine Corps' Installations and Logistics Command.

The second step in the cost-benefit analysis is to determine standing. Specifically, we must determine what costs and benefits are relevant to this analysis. When analyzing the maintenance costs of a vehicle, we could look at it as narrowly as the individual unit, or we could broaden it all the way to the manufacturer or the taxpayer. In this analysis, we consider both the costs of the individual unit operating a single MTRV as well as to the Marine Corps as a whole, operating the entire fleet. We also must determine what maintenance operations to consider in the study. Our three options primarily address preventive maintenance. Corrective maintenance may or may not be left off the analysis, as it is a different operation all together (Boardman et al., 2011). We discount corrective maintenance and focus solely on the available preventive maintenance programs.

Once we have identified standing, the next step in the process is to identify and catalog impacts. These impacts can be positive or negative. Positive impacts are categorized as benefits, and negatives are attributed as costs. Once these categories are

established, we must set some standard for measurement of each of the impacts and how they will behave over the life of the project. Costs and benefits can then be monetized and discounted to determine the present value of each (Boardman et al., 2011).

After determining the present value of the impacts, we must test the robustness of the results by conducting a sensitivity analysis. The sensitivity analysis involves altering in reasonable ranges the assumptions used in our analysis; some examples of variables that can be subject to sensitivity analysis are discount rates, ratios of different types of maintenance, and different ranks of maintenance technicians. This process accounts for some of the uncertainty in predicting future maintenance costs (Boardman et al., 2011).

The last step in the process is to make a recommendation, based on the results of our analysis. Specifically, after the entire cost–benefit analysis is complete, we identify one option or combination of options that will deliver the largest cost saving over the relevant time horizon. Because of time and resource limitations, our recommendations also include suggestions for further research. Issues such as the required manning involved in the recommended maintenance solution are outside of our expertise and are left to the manpower professionals (Boardman et al., 2011).

B. COST-BASED ANALYSIS

Our study compares costs only, assuming benefits delivered by each alternative are the same. Therefore, the methodology followed in this study is a special case of a cost–benefit analysis, where only costs are compared from each alternative. Such methodology is known as a cost-based analysis.

We began our research by looking at the maintenance program currently in practice, PMCS. For this phase, we turned to the current publications and Global Combat Support System-Marine Corps (GCSS-MC). This provided us with a baseline of specific maintenance actions that are performed at each interval in the PMCS structure (Boardman et al., 2011).

To support our research, we conducted a site visit with a unit at Camp Pendleton, CA that operates the MTRV. During this visit, we gained access to experienced

maintenance planners and technicians who provided us with access to data and explanation as required. Also during this visit, we observed certain maintenance actions to better understand and quantify the time required to complete an action.

Using established estimates of manpower costs and specified and observed time to complete maintenance actions, we were able to quantify the cost of a particular check to the Marine Corps. In our analysis, we project these costs out over the 22-year lifespan of the MTVR using appropriate financial measures.

The same basic method applied to analyzing the ASP. Prior to inducting a vehicle into administrative storage, certain maintenance actions must be performed. While the vehicles are in storage, actions must be taken on a regular basis, and maintenance must be again performed upon each vehicle's removal. We observed some of these actions during our site visit to Camp Pendleton. A cost was estimated for these actions in the same manner as for the PMCS program. We performed sensitivity analysis on this portion of the program by varying the length of its lifespan that a vehicle spends in storage.

The Marine Corps currently manages the rotation of its assets between operational units and large storage units such as logistics bases and maritime prepositioning. Simply adjusting the schedule at which these assets are rotated between activities may produce some savings. We did not look at this program. Our goal is a cost analysis, not an optimization model.

THIS PAGE INTENTIONALLY LEFT BLANK

V. COST-BASED ANALYSIS OF PREVENTIVE MAINTENANCE CHECKS AND SERVICES

The current practice for vehicle maintenance is the preventive maintenance checks and services (PMCS) program. Our goal with this program is to attempt to quantify the cost of operating this program for the vehicle fleet over the life cycle. We will do the same for the ASP.

In order to develop a cost estimate of this program, we reviewed the Marine Corps Order (MCO) 4790.2C, which is the Marine Corps' overarching maintenance manual. In addition, we conducted a site visit to better understand the actual operations at the unit level that operates the MTRV.

During this visit, we observed the operation of the MTRV and the associated maintenance procedures and inspections. We also interviewed the mechanics and scheduling personnel to better understand the time requirements of completing the administrative tasks surrounding each maintenance evolution. Therefore, the manpower requirements presented in this chapter reflect both the technical manual requirements and our own estimates of actual requirements based on these discussions.

All manpower costs are derived from the fiscal year (FY) 2013 military composite standard pay and reimbursement rates (U.S. Marine Corps, 2012b). Each calculation assumes an average of approximately 171 hours worked per month.

A. MAINTENANCE PROCEDURES

A battalion that operates the MTRV will conduct six basic maintenance functions: pre-operational checks, first echelon scheduling, second echelon scheduling, monthly checks, annual checks, and quality control. We first describe each of these functions. Once the processes are identified, we establish costs for each. Personnel in multiple pay grades can complete each process. Based on our site visit and the experience of the author, we applied a weighted average to reflect the most likely combination that would be used to complete each function. This produces a more realistic estimation of costs involved.

1. Pre-Operations Check

Prior to any vehicle being driven, a pre-operations check must be completed. This occurs each time the vehicle is operated. The echelon one scheduler (company level) will determine which vehicles are going to be used in a particular day and the drivers for those vehicles. Once the vehicles are scheduled, the pre-operations check must be completed. We estimate that an average unit will conduct 150 pre-operations checks on an individual vehicle each year.

There are two people required to complete the pre-operations check: the driver and a quality control representative. Our observed unit utilizes one specific individual, a corporal, to act as quality control for every vehicle that is driven. The quality control representative will then proceed with the driver to the designated vehicle with the pre-operations checklist to conduct the check. The tasks to be completed are listed in Table 1.

Table 1. Pre-operations Check Actions and Labor Required

Task	Hours
Inspect cab and hood	1.0
Inspect fuel tank	0.1
Inspect fuel/water separator	0.2
Check transmission fluid level	0.1
Inspect air dryer / after cooler	0.2
Inspect air system	0.1
Inspect tires	0.3
Inspect cargo body and ISO locks	0.6
Inspect cargo body cover, troop seats, bows, staves and brackets	0.2
Inspect windshield washer fluid bottle	0.1
Inspect coolant over flow tank and coolant level	0.1
Inspect windshield wiper arms and blades	0.1
Inspect lights and reflectors	0.8
Inspect windshield and glass	0.8
Check engine oil	0.2
Inspect ether start system	0.1
Inspect hydraulic steering system	0.1
Inspect undercarriage and frame	0.3
Check engine starter	0.1
Inspect exhaust system	0.4
Total	5.9

In practice, the quality control representative will complete this check on every vehicle scheduled for that day with the vehicle's designated driver. A driver can be anyone who is qualified from pay grades E-1 through E-5. The weighted average of ranks is presented in Table 2.

Table 2. Weights Used in Labor Cost Calculations

Rank	Pre-operations check	Scheduling—1st echelon	Scheduling—2nd echelon	Monthly	Annual
E-1	0.1	-	-	0.1	0.1
E-2	0.3	-	-	0.35	0.2
E-3	0.3	-	-	0.35	0.4
E-4	0.2	0.4	0.1	0.15	0.25
E-5	0.1	0.5	0.2	0.05	0.05
E-6	-	0.1	0.5	-	-
E-7	-	-	0.2	-	-
Total	1.0	1.0	1.0	1.0	1.0

If the pre-operations check were completed in the time allotted in the technical manual, it would take the driver a total of 5.9 hours to complete (CMC, 1994). During our site visit, we observed this check being completed by three vehicle operators. In practice, all of the above items took an average of 11 minutes, or 0.183 hours, to complete. Since two operators are used to complete this check, it would total 22 minutes or 0.366 man-hours.

Using the weighted average for manpower costs, each pre-operations check costs \$9.34. This includes both personnel completing the check. Since there are no parts required, the cost for each check only includes the time of the personnel. Given our estimate of 150 checks performed each year on a single vehicle, the annual cost is \$1,400.73. If a unit followed the technical manual (TM) requirements for the pre-operations check and expended the entire 5.9 man-hours, the cost would increase to \$150.53 per check and \$22,580.13 per year for each vehicle in the inventory.

2. Scheduling–First Echelon

Maintenance completed at the 1st echelon level is limited to basic daily and monthly service and lubrication and limited troubleshooting. Qualified truck operators perform these services at the company level. The scheduling is likewise completed at the company by an E-4 to E-6.

3. Scheduling–Second Echelon

Second echelon, or battalion level, maintenance is more involved than that performed at the 1st echelon. These services can also include daily and monthly inspections, but expand to annual inspections. Services are performed by mechanics that are qualified to use diagnostic tools to perform more complex repairs. The scheduling of these services is completed by anyone from E-4 to E-7. It is estimated that the scheduling takes approximately 25 minutes to complete. This includes planning and actual input of the schedule into a computer system.

4. Monthly

Monthly maintenance services are performed on each vehicle. The checks and services performed at this interval are greater in detail than the pre-operations check. A mechanic from E-1 to E-5 would normally complete maintenance at this interval. Each vehicle experiences 12 monthly inspections per year. The technical manual requirements are listed in Table 3 and total 9.8 hours to complete. Based on our estimate, this maintenance can be completed in 1.25 hours. In addition to the man-hours, this interval requires an amount of lubricant, grease, automotive and artillery (GAA). GAA costs are \$32.43 per monthly PMCS performed.

Table 3. Monthly PMCS Actions and Labor Required

Task	Hours	Task	Hours
Inspect cab and hood	1.0	Inspect turbocharger	0.5
Inspect Fuel Tank	0.1	Inspect coolant overflow tank and coolant level	0.1
Inspect fuel/water separator	0.2	Inspect radiator and coolant hoses	0.2
Inspect Batteries/box	1.0	Inspect cooling fan and fan belt	0.2
Inspect air dryer/after cooler	0.2	Fuel filter and fuel pump	0.2
Inspect air system	0.8	Check Engine oil	0.2
Inspect tires	0.3	Inspect ether start system	0.1
Inspect shocks	0.1	Inspect hydraulic steering system	0.4
Inspect mud flaps	0.1	Inspect undercarriage and frame	0.5
Inspect front/rear inter-vehicle electrical connector	0.1	Inspect anti-sway bar	0.1
Inspect front/rear glad hands	0.2	Check engine starter	0.1
Inspect cargo body and ISO locks	0.6	Inspect exhaust system	0.4
Inspect cargo body cover, troop seats, bows, staves, and backrests	0.2	Inspect CTIS	0.1
Inspect vent hoses and transmission breather	0.2	Inspect cab interior	1.0
Inspect oil filter and oil sampling valves	0.2	Inspect air compressor	0.2
Air intake system	0.2	Total	9.8

Using the same weighted average from Table 2, the cost of each monthly PMCS, including the required parts, is \$103.03. This check is completed 12 times each year for an annual cost of \$1,236.37. The TM labor cost, from Table 3, totals 9.8 man-hours. If this figure was used, the total cost of the monthly inspection would be \$313.47, or \$3,761.66 per year.

5. Annual

The annual checks and services are presented in Table 4 and are completed once each year. A mechanic from E-1 to E-5 would normally complete this maintenance in accordance with the weights provided in Table 2. The technical manual provides for 9.8 man-hours to complete the annual service. Our estimate for the annual check is 9.53 man-hours. Additional parts costs for the annual total \$654.50. The total cost of an

annual PMCS, including parts and labor, is \$951.68. The labor provided by the TM, depicted in Table 4, totals 18.6 man-hours. Assuming this labor cost, the total cost of an annual inspection rises to \$1,182.72.

Table 4. Annual PMCS Actions and Labor Required

Task	Hours	Task	Hours
Inspect cab and hood	1.0	Air intake system	0.2
Inspect Fuel Tank	0.1	Inspect turbocharger	0.5
Inspect fuel/water separator	0.2	Inspect coolant overflow tank and coolant level	0.1
Inspect Batteries/box	1.0	Inspect radiator and coolant hoses	0.2
Inspect air dryer/after cooler	0.2	Inspect cooling fan and fan belt	0.2
Inspect air system	0.8	Fuel filter and fuel pump	0.2
Inspect tires	0.3	Check Engine oil	0.2
Inspect shocks	0.1	Inspect ether start system	0.1
Inspect mud flaps	0.1	Inspect hydraulic steering system	0.4
Inspect front/rear inter-vehicle electrical connector	0.1	Inspect undercarriage and frame	0.5
Inspect front/rear glad hands	0.2	Inspect anti-sway bar	0.1
Inspect cargo body and ISO locks	0.6	Check engine starter	0.1
Inspect cargo body cover, troop seats, bows, staves, and backrests	0.2	Inspect exhaust system	0.4
Inspect vent hoses and transmission breather	0.2	Inspect CTIS	0.1
Inspect oil filter and oil sampling valves	0.2	Inspect cab interior	1.0
		Inspect air compressor	0.2
		Total	9.8

B. CHAPTER SUMMARY

Costs for each PMCS check were estimated based on the parts and labor required for each check. This research began as a study of the MCO 4790.2C to estimate costs associated with preventive maintenance. However, we have estimated costs based both on the technical manual labor requirements and our own estimates of actual requirements based on our site visit. We found significant differences between the TM requirements and the actual requirements for PM. This difference leads to unpredictable cost

incurrence due to the lack of standardization among units. Most units probably conduct maintenance as observed at Camp Pendleton. However, some units may adopt a strict by-the-book policy leading to different cost structures for the same maintenance. We provide analysis of both scenarios to highlight the potential differences that exist.

THIS PAGE INTENTIONALLY LEFT BLANK

VI. COST-BASED ANALYSIS OF ADMINISTRATIVE PROGRAMS

The Marine Corps provides options to units to place a portion of its equipment in long-term storage rather than maintain it in the normal PMCS system. This administrative storage program (ASP) is delegated to each Marine expeditionary force (MEF) commander and is given different names by each MEF (i.e., left behind storage program, I MEF). Because of these differences, for simplicity we refer to the ASP to cover all related programs. The other option available to commanders is the administrative deadline (ADL). The general guidance for the ASP and ADL is provided by MCO 4790.2C. This order delineates the general requirements for a piece of equipment to be placed in storage.

A. ADMINISTRATIVE STORAGE

The ASP is provided by the Marine Corps as a program to be maintained at the MEF level. Equipment can be placed in the ASP for a period of 12-30 months and must be in condition code “A” (mission capable) when inducted. Once in storage, the equipment must be inspected quarterly and have any due PMCS completed upon removal (CMC, 1994).

Each MEF has established further procedures for placing equipment in the ASP. It is important to note that at the time of this writing, two of the three MEFs were operating without signed orders—only drafts. Each MEF was allowed to establish its own procedures to best serve its individual needs. This has created some variation in the system.

As an example, I MEF requires owning units to nominate equipment for the ASP via letter to the commanding general. Once this is approved, the unit must coordinate with the ASP personnel to conduct an initial inspection of the equipment at the owning unit. The ASP personnel will identify any corrective actions that must be taken by the owning unit prior to the equipment being able to be placed in storage. Once these identified issues are corrected, the equipment can be delivered to the ASP personnel,

where personnel will conduct a final inspection for induction to verify the previous corrections. The equipment must also have had its annual preventive maintenance performed within the previous 30 days. If this is not current, the annual PM must be repeated. Once inducted into the ASP, the equipment is required to be visually inspected and exercised monthly. ASP personnel conduct these actions (USMC, n.d.).

When the owning unit desires to remove the equipment from the ASP, it must submit a letter of notification of removal. I MEF allows for periods from 6–18 months in the ASP. In order to remove the equipment from the ASP, the owning unit must conduct a joint limited technical inspection with the ASP personnel to verify the status of the equipment and complete an annual PM immediately upon removal (USMC, n.d.).

The estimate of costs associated with the ASP is broken up into three categories: pre-storage, during storage, and post-storage. Pre-storage costs include everything that both the owing unit and the ASP personnel must complete to get a vehicle inducted into the ASP. During storage costs include the periodic inspections and exercise of equipment completed after induction to the ASP. Post-storage costs capture the requirements of the owning unit to notify the ASP of removal and associated inspections required to return the equipment to full operational status.

1. Pre-Storage Costs

Pre-storage actions include the issuance of the request letter; initial inspection; final induction inspection; admin follow up; and annual inspection, if required. Because at any given time only 1/12th of a unit's vehicle fleet is within the required 30-day window on the annual inspection, we estimate that an additional annual inspection will be required on 91.6 percent of vehicles inducted into the ASP. In addition to this, we include a monthly PMCS. These two checks have different steps so the monthly must be completed prior to the annual. The total cost to induct one MTRV into the ASP is \$1,157.24.

2. During Storage Costs

Once a vehicle is inducted into the ASP, the only cost requirements are a monthly visual inspection and exercise of the equipment. This normally consists of starting the vehicle to ensure its operation. The inspection and exercise take 0.1 and 0.2 hours, respectively, and are conducted by ASP personnel. These actions require no parts and cost \$16.35 per month that the vehicle is in storage.

3. Post-Storage Costs

Removing a vehicle from the ASP requires notification by the owning unit, a joint inspection, and an annual PMCS inspection on every vehicle upon removal. The total cost for this process is \$1,115.73. These costs are unavoidable since the associated actions are required by the instructions governing the ASP (USMC, n.d.). Table 5 provides a summary of costs incurred through the ASP cycle.

Table 5. Periodic Administrative Storage Costs Given Length of Time in the ASP

Action	Cost (CY13\$)				
	6 Month	12 Month	18 Month	24 Month	30 Month
Year 1:					
Monthly PMCS	103.03	103.03	103.03	103.03	103.03
Annual PMCS required (91.6%)	871.74	871.74	871.74	871.74	871.74
ASP Request letter	10.82	10.82	10.82	10.82	10.82
Initial Inspection	159.97	159.97	159.97	159.97	159.97
Final induction inspection	159.97	159.97	159.97	159.97	159.97
Admin Follow-up for induction	8.06	8.06	8.06	8.06	8.06
Monthly visual inspection (year 1)	23.78	47.56	47.56	47.56	47.56
Monthly exercise (year 1)	74.31	148.62	148.62	148.62	148.62
Weekly Report	166.50	333.00	333.00	333.00	333.00
Subtotal year 1	1,578.18	1,842.77	1,842.77	1,842.77	1,842.77
Year 2:					
Monthly visual inspection (year 2)	-	-	23.78	47.56	47.56
Monthly exercise (year 2)	-	-	74.31	148.62	148.62
Weekly Report	-	-	166.50	333.00	333.00
Subtotal year 2	-	-	264.59	529.18	529.18
Year 3:					
Monthly visual inspection (year 3)	-	-	-	-	23.78
Monthly exercise (year 3)	-	-	-	-	74.31
Weekly Report	-	-	-	-	166.50

Subtotal year 3					264.59
Removal:					
Admin notification for removal	4.10	4.10	4.10	4.10	4.10
Joint LTI	159.97	159.97	159.97	159.97	159.97
Annual PMCS Required (100%)	951.68	951.68	951.68	951.68	951.68
Subtotal removal	1,115.75	1,115.75	1,115.75	1,115.75	1,115.75
Total	2,693.93	2,958.52	3,223.11	3,487.70	3,752.29

B. ADMINISTRATIVE DEADLINE

The administrative deadline program (ADL) is also authorized by MCO 4790.2C. This program is similar to the ASP in that it provides units as an option to store unneeded gear on a long-term basis outside of the normal maintenance reporting system. This equipment will not be used when it is placed in the ADL, and certain requirements must be met prior to placing it in the ADL. Unlike the ASP, where the equipment is sent to a third party, the ADL equipment is maintained at the owning unit for the period of storage.

Current guidance allows a unit to place equipment in the ADL for a period between six and 12 months. The equipment must be in working order when placed in the ADL and, like the ASP, must have had an annual inspection within 30 days of being inducted. While in the ADL, the equipment must be inspected monthly and exercised quarterly. In conjunction with this quarterly exercise a daily (pre-operations) check must also be performed. Upon removal of the equipment, the ADL program requires all PMCS checks performed that are due at the time of removal.

1. Pre-Storage Costs

When inducting a vehicle into the ADL, the pre-storage requirements are less than those of the ASP. The unit, since it is maintaining custody of the vehicle, can forgo the requests and inspections that must be done with the ASP. Therefore, the only cost associated with pre-storage in the ADL is ensuring the vehicle has had an annual inspection within 30 days of storage. We use the same estimate for this cost as with the ASP, \$871.74.

2. During Storage Costs

While in the ADL, the equipment must be visually inspected monthly and exercised quarterly. When the vehicle is exercised, a daily inspection must also be performed. This cost is captured in the pre-ops checks in chapter V.

3. Post-Storage Costs

Removing a vehicle from the ADL requires completion of only those PMCS checks that are due at the time of removal. This differs from the ASP, where an immediate annual inspection is required. The annual inspection will only be required upon removal from the ADL if the length of storage was 11 months or more, if the last annual was performed within 30 days of induction. Shorter periods will only require a monthly inspection upon removal.

C. CHAPTER SUMMARY

The amount of time each vehicle spends in the ASP or ADL can vary. Instructions allow for intervals between 6 and 30 months in the ASP and 6 to 12 months in the ADL (USMC, 1994; USMC, n.d.). Pre- and post-storage costs are fixed for each vehicle. Every step in the process must be completed for each vehicle to be placed into and removed from storage. Inspection costs are variable, based on how much time a vehicle spends in the ASP. Table 5 presents the total costs of the ASP and ADL for storage periods of 6, 12, 18, 24 and 30 months. Understanding that the order only allows the ADL for 6 to 12 months, we have included the longer periods allowed by the ASP to gain a side-by-side comparison of these programs. During storage costs are broken up by year in storage. This aids in establishing the time period in which the costs are incurred. Doing this aids in calculating the net present value of the program that is done in Chapter VIII.

THIS PAGE INTENTIONALLY LEFT BLANK

VII. ANALYSIS OF FINDINGS

The goal of this research was to help determine a method for the Marine Corps to manage its excess capacity in its vehicle fleet during peacetime. In order to do this, we analyzed the costs associated with maintaining a vehicle in the normal PMCS system over its life cycle and compared that to the costs of storing the vehicle for some percentage of its life. In doing so, we hoped to determine the most effective combination of these two programs.

We began by determining the costs associated for each program as described in Chapters VI and VII. We did this based on managing a single vehicle. There are some economies of scale that may be applied to the steps, but as many disparate units operate the MTRV, all with different operational needs, these economies cannot be accurately predicted within the confines of this study.

A. ADMINISTRATIVE STORAGE PROGRAM VERSUS PREVENTIVE MAINTENANCE

Current Marine Corps policy allows that a vehicle may be placed in the ASP for periods ranging from six to 30 months. Based on this policy, we determined the costs associated with placing a vehicle into the ASP, maintaining it while in storage, and removing it at six-month intervals within the allowable range. We then calculated the net present value (NPV) of these costs over the 22-year life cycle of the MTRV. This cost was compared to the NPV of keeping the vehicle at the owning unit and maintaining it in accordance with the PMCS program.

The next question to address was what percentage of the fleet to place in the ASP at any given time. We conducted a sensitivity analysis to determine which combination of the ASP and PMCS makes the most sense. We made calculations based on an MTRV placed in the ASP for zero percent, 10 percent (2.2 years), 20 percent (4.4 years) and 30 percent (6.6 years) of its life. These ASP intervals would be spread out evenly throughout the life cycle.

In order to calculate the NPV, we determined the total costs for either preventive maintenance or the ASP that would be incurred over the life of the vehicle. A 0.8 percent discount rate was applied to the full 22-year program (Office of Management and Budget [OMB], 1992). To start out, the cost of operating one MTRV in the PMCS system for 22 years with no time in the ASP is \$72,132 (calendar year (CY) 13\$). If the MTRV were placed in the ASP for a period of six months throughout its life, the cost would change to \$81,881 (CY13\$). This number was calculated by assuming that in the years that the vehicle is not placed in the ASP, the normal PMCS costs apply. In those years where the vehicle is placed in the ASP, it will spend half the year in storage. Therefore, half of the PMCS costs will be incurred plus the costs to place the vehicle in the ASP, maintain it for six months, and remove it at the end of the period. We applied similar methodology to the other applicable storage intervals. The annual PMCS cost is about \$3,589. So, in the years the vehicle is in storage, the Marine Corps saves half of this, roughly \$1,795, but simultaneously incurs over \$2,500 in the ASP costs. The complete array of options is presented in Table 6. The costs are calculated to show the net cost or savings for one vehicle through its life. These costs are then expanded to show the costs over the entire MTRV fleet.

Table 6. Comparative Costs Between PMCS and the ASP at Given Intervals (CY13\$)—22-Year Program

30% of Life Cycle in ASP (6.6 years total)

ASP Interval	PMCS Only	ASP at Given Interval	Per vehicle (Cost)/Savings over PMCS only	Fleet (Cost)/Savings over PMCS only
6 Months	\$72,132.00	\$84,920.04	(\$12,788.04)	(\$115,092,351.16)
12 Months	\$72,132.00	\$68,766.98	\$3,365.02	\$30,285,197.68
18 Months	\$72,132.00	\$62,778.92	\$9,353.08	\$84,177,752.65
24 Months	\$72,132.00	\$59,586.33	\$12,545.68	\$112,911,088.02
30 Months	\$72,132.00	\$58,204.59	\$13,927.41	\$125,346,713.35

20% of Life Cycle in ASP (4.4 years total)

ASP Interval	PMCS Only	ASP at Given Interval	Per vehicle (Cost)/Savings over PMCS only	Fleet (Cost)/Savings over PMCS only
6 Months	\$72,132.00	\$80,337.56	(\$8,205.56)	(\$73,850,071.17)
12 Months	\$72,132.00	\$69,709.49	\$2,422.51	\$21,802,574.65
18 Months	\$72,132.00	\$66,476.69	\$5,655.31	\$50,897,780.80
24 Months	\$72,132.00	\$62,301.12	\$9,830.88	\$88,477,907.31
30 Months	\$72,132.00	\$62,765.10	\$9,366.90	\$84,302,085.74

10% of Life Cycle in ASP (2.2 years total)

ASP Interval	PMCS Only	ASP at Given Interval	Per vehicle (Cost)/Savings over PMCS only	Fleet (Cost)/Savings over PMCS only
6 Months	\$72,132.00	\$76,689.77	(\$4,557.77)	(\$41,019,909.79)
12 Months	\$72,132.00	\$70,701.84	\$1,430.16	\$12,871,456.87
18 Months	\$72,132.00	\$68,436.60	\$3,695.41	\$33,258,645.61
24 Months	\$72,132.00	\$65,708.11	\$6,423.89	\$57,815,003.27
30 Months	\$72,132.00	\$67,431.68	\$4,700.32	\$42,302,859.09

As shown in Table 6, the most cost-effective option is to place 30 percent of the vehicle fleet in the ASP at intervals of 30 months at a time. These intervals would be spread evenly across the life of the vehicle. This outcome makes sense, as the more time spent in storage minimizes the amount of preventive maintenance completed over the life cycle. However, placing a vehicle in the ASP and leaving it there for 30 months may not always be practical. Table 6 provides the analysis of all available options under the ASP. This shows the options that are cost effective over leaving a vehicle in the possession of the owning unit subject to the PMCS system.

Analysis shows that no matter what portion of the life cycle is placed in the ASP, an interval of six months is not cost effective. In the long run, if the resources are

expended to place a vehicle in the ASP and it is removed in that short time period, the ASP will ultimately cost more to maintain than keeping vehicles with the owning unit. Over the entire MTRV fleet, these extra costs add up to hundreds of millions of dollars. This analysis is based on a new acquisition program with 22 years left in the life cycle. The MTRV program is currently about halfway through its life cycle. The next question for us to address is how to manage this program for the remainder of its life.

Table 7. Comparative Interval Costs—12-Years Remaining

30% of Life Cycle in ASP (6.6 years total)

ASP Interval	PMCS Only	ASP at Given Interval	Per vehicle (Cost)/Savings over PMCS only	Fleet (Cost)/Savings over PMCS only
6 Months	\$42,786.72	\$50,748.86	(\$7,962.15)	(\$71,659,324.46)
12 Months	\$42,786.72	\$40,687.00	\$2,099.72	\$18,897,461.56
18 Months	\$42,786.72	\$36,648.45	\$6,138.26	\$55,244,370.77
24 Months	\$42,786.72	\$32,107.18	\$10,679.53	\$96,115,807.97
30 Months	\$42,786.72	\$32,606.25	\$10,180.46	\$91,624,161.79

20% of Life Cycle in ASP (4.4 years total)

ASP Interval	PMCS Only	ASP at Given Interval	Per vehicle (Cost)/Savings over PMCS only	Fleet (Cost)/Savings over PMCS only
6 Months	\$42,786.72	\$50,748.86	(\$7,962.15)	(\$71,659,324.46)
12 Months	\$42,786.72	\$40,687.00	\$2,099.72	\$18,897,461.56
18 Months	\$42,786.72	\$36,648.45	\$6,138.26	\$55,244,370.77
24 Months	\$42,786.72	\$32,107.18	\$10,679.53	\$96,115,807.97
30 Months	\$42,786.72	\$32,606.25	\$10,180.46	\$91,624,161.79

10% of Life Cycle in ASP (2.2 years total)

ASP Interval	PMCS Only	ASP at Given Interval	Per vehicle (Cost)/Savings over PMCS only	Fleet (Cost)/Savings over PMCS only
--------------	-----------	-----------------------	---	-------------------------------------

6 Months	\$42,786.72	\$45,774.76	(\$2,988.04)	(\$26,892,371.19)
12 Months	\$42,786.72	\$41,736.33	\$1,050.38	\$9,453,443.34
18 Months	\$42,786.72	\$40,744.73	\$2,041.99	\$18,377,917.93
24 Months	\$42,786.72	\$39,228.08	\$3,558.63	\$32,027,704.00
30 Months	\$42,786.72	\$37,691.42	\$5,095.30	\$45,857,686.82

Table 7 shows the costs associated with the PMCS and the ASP in an MTRV program with 12 years remaining in its life cycle. This more closely reflects the current standing of the MTRV program. We determined costs in the same method as the full acquisition program, with the exception of applying a 0.1 percent discount rate because of the shorter time horizon (OMB, 1992). Our research shows similar results for the remainder of the program as for a new acquisition. Utilizing the ASP for a six-month interval is shown to not be cost effective under either circumstance. The Marine Corps only saves money by placing a vehicle in storage for a period of at least 12 months. Table 8 expands these costs to the entire MTRV fleet; it shows that regardless of what proportion of the fleet is placed in the ASP, it must be at least a 12-month period of storage in order to be cost effective.

Table 8. Total Cost to Maintain MTRV Fleet Given Combinations of the PMCS and ASP

Total Life-Cycle Cost (CY13M\$)

% PMCS	100%	90%		80%		70%	
% ASP	0%	10%		20%		30%	
6 Months	\$15.701	\$16.578	(5.59%)	\$17.455	(11.17%)	\$18.333	(16.76%)
12 Months	\$31.402	\$30.940	1.47%	\$30.479	2.94%	\$30.018	4.41%
18 Months	\$47.103	\$45.303	3.82%	\$43.503	7.64%	\$41.703	11.46%
24 Months	\$62.804	\$59.665	5.00%	\$56.527	9.99%	\$53.388	14.99%
30 Months	\$78.505	\$74.027	5.70%	\$69.550	11.41%	\$65.073	17.11%

Our analysis shows that the ASP, while a useful tool, is subject to limitations. The cost effectiveness of this program is based on the length of time a vehicle spends in storage and the costs associated with inducting and removing the vehicle from the ASP. Under the current cost structure, the ASP will be an effective method of managing excess capacity in the MTRV fleet only if the vehicles are stored at intervals exceeding 12 months. If this option is determined to be unfeasible by commanders, the vehicles should be maintained under the existing PMCS system by the owning unit.

B. ADMINISTRATIVE DEADLINE

Current Marine Corps policy allows for the ADL program to be utilized for periods between six and 12 months. When placed in the ADL, a vehicle is maintained at the owning unit rather than transferred to a third party for storage. This eliminates or reduces many of the costs associated with the ASP. The vehicle is still required to be in a mission-capable status when placed in the ADL. This is significant, as the requirement prevents units from placing broken down or neglected equipment in the ADL simply to remove it from the normal reporting process. Table 9 shows the fleet cost to maintain different percentages of the MTRV fleet in the ADL.

Table 9. Total Cost to Maintain MTRV Fleet Given Combinations of PMCS and the ADL

Total Life-Cycle Cost (CY13M\$)							
% PMCS	100%	90%		80%		70%	
% ADL	0%	10%		20%		30%	
6 Months	\$15.701	\$15.119	3.70%	\$14.538	7.40%	\$13.958	11.1%
12 Months	\$31.402	\$30.122	4.08%	\$28.842	8.15%	\$27.562	12.23%
18 Months	\$47.103	\$44.292	5.97%	\$41.480	11.94%	\$38.669	17.90%
24 Months	\$62.804	\$58.461	6.91%	\$54.118	13.83%	\$49.776	20.74%
30 Months	\$78.505	\$72.630	7.48%	\$66.756	14.96%	\$60.882	22.45%

Since a vehicle placed in the ADL does not need to be transferred to a third party, there is no need for the multiple inspections required with the ASP. If another entity is going to assume responsibility for the equipment, inspections make sense to ensure that the storage entity is accepting equipment that meets the requirements of the program. With the ADL, custody of the equipment never changes, so the responsibility for storing a mission-ready vehicle remains with the owning unit.

C. SUMMARY

Both the ASP and ADL have potential for cost savings over the PMCS system. These savings however, can only be realized under certain circumstances. Units operating the MTRV must undertake careful planning to ensure the most efficient use of these vehicles.

TABLE 10. Maintenance Costs by Programs per Single MTRV for Given Interval

Interval (months)	Cost (FY13\$)				
	PMCS (Actual)	PMCS (TM)	ASP (Actual)	ASP (TM)	ADL
6	1,794.39	5,741.90	2,796.39	3,000.94	1,130.31
12	3,588.78	34,451.41	3,061.55	3,066.57	2,126.18
18	5,383.17	68,902.81	3,326.13	3,132.19	2,170.37
24	7,177.56	103,354.22	3,590.72	3,197.82	2,214.56
30	8,971.95	172,257.03	3,855.31	3,263.44	2,258.75

As a result of the reduced costs, the ADL program's total cost is much less than that of the ASP; the differences are in the range of 40 to 60 percent. Allowing the owning unit to maintain its equipment in a combination of the PMCS and ADL is the most cost effective. Table 10 breaks down the cost of each program for intervals ranging from 6 to 30 months. For example, the cost of maintaining a single MTRV in the PMCS system is \$1,794.39 (FY13\$). This cost includes the expected number of pre-operations checks, monthly inspections, and the amortized cost of the annual inspection. This figure assumes the estimated labor required based on our site visit at Camp Pendleton. For comparison, we have also presented the cost with the labor requirements as depicted in

the TM. Keeping with the previous example, if a unit followed the labor requirements as depicted in the TM, the cost to operate that same MTVR in the PMCS system for six months would increase to \$5,741.90 (FY13\$).

VIII. CONCLUSIONS AND RECOMMENDATIONS

The goal of this study was to analyze current preventive maintenance programs used by the Marine Corps for the MTVR. In doing so, we aimed to find a cost-effective method for managing excess capacity in the MTVR fleet during peacetime. We compared life-cycle costs of the current PMCS system, the administrative storage program, and administrative deadline using a cost-based analysis approach.

All three of these programs have potential uses and can provide benefits to the Marine Corps in terms of cost savings. The ASP however, is subject to limitations. Inducting vehicles into the ASP only realizes cost savings when stored for periods of at least 12 months. Any shorter period of storage as currently used in some MEFs, results in increased costs of up to approximately 17 percent over the program's life cycle. If vehicles only need removed from service for a short time, it is more efficient to utilize the ADL or keep them on the lot in the PMCS system.

The ADL program is cost effective both in the short as well as the long run of the life cycle. Due to the fewer requirements and custody transfers involved with the ADL, this program realizes significant cost savings over maintaining a vehicle in the PMCS system or the ASP. The ADL also has the added benefit of allowing the commander flexibility with equipment that is not available when it is transferred into another unit's custody. Again, we looked at this program through the lens of peacetime operations, so left-behind equipment is not a factor. The utility of the ADL arises when a unit is conducting normal peacetime training and garrison operations. In this scenario, the commander is provided maximum flexibility by being able to utilize the ADL for a unit's excess vehicles, but also maintains authority over these vehicles. The commander can then pull equipment out of the ADL and place it in service as the need arises without incurring excessive costs.

A. RECOMMENDATIONS

Our goal in this analysis was to examine options available to the Marine Corps in preventive maintenance. By analyzing these programs, we provide the Marine Corps

options to manage its fleet of MTRVs in the most efficient manner during peacetime. Our recommendations include some that can be considered right away and some that will require further research.

1. Recommendations for Marine Corps Logistics Command

Our recommendations for Marine Corps Logistics Command that can be considered right away include:

1. Standardization of the ASP throughout the Marine Corps
2. Expansion of the ADL

While this issue does require more study, we conclude based on the results of our analysis that there are actions that can be taken by the Marine Corps to help manage its maintenance costs. The first issue that we found lies in the variation in ASPs. Each MEF was given room to tailor the ASP to its own needs with only a few guidelines. The result of this decision has been significant differences in the ASP requirements (i.e., multiple inspections), incurring unpredictable and potentially unnecessary costs. Standardization of the ASP across the Marine Corps will provide for more predictability and may avoid unnecessary expenditures.

Second, our analysis results point towards a review of the ADL program. Expansion of this program, under a standard process as proposed above, can allow individual commanders flexibility in maintaining equipment. These battalion-level commanders know best their units' requirements and can store unnecessary equipment at minimal cost. The ADL program already requires equipment be mission ready when placed in storage. Marine Corps Logistics Command could oversee this program with periodic audits of individual units to ensure the ADL program is not being abused by local commanders.

2. Recommendations for further research

Ultimately, this research is merely the beginning of a complete analysis of Marine Corps maintenance programs. There are some actions that can be taken to increase efficiency in the storage programs.

Further research must be conducted prior to making any policy decision.

We have three recommendations for further research.

1. First, determine the effect of the ASP and ADL on corrective maintenance. This study focused purely on preventive maintenance. While placing vehicles in storage realizes significant cost avoidance, we do not know the effect on the vehicles remaining in use. While a certain percentage of the fleet is in storage, these remaining vehicles will see increased use. What effect this increase has on the frequency and severity of corrective maintenance cannot be determined within the bounds of this study.

2. Second, determine the optimal manning requirements under the preferred maintenance plan. Changing any maintenance plan or number of available vehicles in a unit will also change the manpower requirements of that unit. With fewer vehicles in the PMCS system, a unit's requirement for operators and mechanics will change. Conducting a detailed study of the manning required for combinations of the programs discussed will aid in predicting the true costs to operate the fleet.

3. Lastly, conduct further research on condition-based maintenance (CBM). Our original goal in entering this study was to include CBM in the analysis. This proved unfeasible considering the time available. The data is not currently available on the MTRV program to allow for a detailed cost analysis based on CBM. Future study might be able to go deeper into the program and focus purely on CBM to better quantify potential savings.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

- Barnes, G., & Langworthy, P. (2003). *The per-mile costs of operating automobiles and trucks* (report no. MN/RC 2003-19). St. Paul, MN: Minnesota Department of Transportation.
- Bateman, J. (1995). Preventive maintenance: Stand-alone manufacturing compared with cellular manufacturing. *Industrial Management* 37(1), 19–21.
- Boardman, A., Greenberg, D., Vining, A., & Weimer, D. (2011). *Cost–benefit analysis concepts and practice* (4th ed.). Boston, MA: Prentice Hall.
- Commandant of the Marine Corps. (1977, August 18). *Marine Corps integrated maintenance management system automated information system, headquarters maintenance subsystem, headquarters user's manual* [Memorandum]. Washington, DC: Headquarters United States Marine Corps.
- Commandant of the Marine Corps. (1994, July 19). *MIMMS field procedures manual* [Memorandum]. Washington, DC: Headquarters United States Marine Corps.
- Commandant of the Marine Corps. (2009, December 23). *Marine Corps total life cycle management (TLCM) of ground weapon systems, equipment and materiel* [Memorandum]. Washington, DC: Headquarters United States Marine Corps.
- Department of Defense. (2012a, October 16). *Condition based maintenance plus (CBM+) for materiel maintenance* [Memorandum]. Washington, DC: Office of the Under Secretary of Defense for Acquisition, Technology, & Logistics.
- Department of Defense. (2012b, April 9). *FY13 Department of Defense (DoD) military personnel composite standard pay and reimbursement rates* [Memorandum]. Washington, DC: Office of the Under Secretary of Defense, Comptroller.
- Department of the Navy (DoN). (2004, January 29). *Memorandum for the assistant deputy undersecretary of defense (maintenance policy, programs and resources)* [Memorandum]. Washington, DC: Headquarters United States Marine Corps.
- Fornasiero, R., Zangiacomi, A., & Sorlini, M. (2012). A cost evaluation approach for trucks maintenance planning. *Production Planning & Control*, 23(2–3), 171–182.
- Goyal, S. K., & Gunasekaran, A. (1992). Determining economic maintenance frequency of a transport fleet. *International Journal of Systems Science*, 23(4), 655–659. doi:10.1080/00207729208949239
- Kiritsis, D., Bufardi, A., & Xirouchakis, P. (2003). Research issues on product lifecycle management and information tracking using smart embedded systems. *Advanced Engineering Informatics*, 17(3–4), 189–202. doi:10.1016/j.aei.2004.09.005

- Haghani, A., & Shafahi, Y. (2002). Bus maintenance systems and maintenance scheduling: Model formulations and solutions. *Transportation Research: Part A: Policy and Practice*, 36(5), 453–482.
- Miller, T., & Bryant, J. (2011). *Medium Tactical Vehicle Replacement (MTVR) and Logistics Vehicle System Replacement (LSVR) programs* [Presentation slides]. Retrieved from http://www.acq.osd.mil/log/mr/psm/14_Industry_and_Govt_Relationship_OSD_PSM_Conf_%20Miller-Bryant_3Nov2011.pdf
- Office of Management and Budget. (1992, October 29). *Guidelines and discount rates for benefit–cost analysis for federal programs* (OMB Circular A-94). Washington, DC: Author.
- Oshkosh Corporation. (2013). Medium tactical vehicle replacement. Retrieved from <http://www.oshkoshdefense.com/products/6/mtvr>
- Under Secretary of Defense for Logistics and Materiel Readiness. (2008). *Condition based maintenance plus DoD guidebook*. Washington, DC: Author.
- United States Marine Corps. (1994). *Integrated logistics support plan for the Marine Corps medium tactical vehicle replacement (MTVR)*. Quantico, VA: author.
- United States Marine Corps. (2005a, August 11). *Marine Corps Logistics Command* [Memorandum]. Washington, DC: author s.
- United States Marine Corps. (2005b, August 11). *Marine Corps total life cycle management (TLCM)* [Memorandum]. Washington, DC: author.
- United States Marine Corps. (n.d.). *Standing operating procedures for left behind storage program (LBSP) for ground tactical equipment* [Memorandum]. Camp Pendleton, CA: Marine Expeditionary Force, Fleet Marine Force.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
Ft. Belvoir, Virginia
2. Dudley Knox Library
Naval Postgraduate School
Monterey, California